Base from U.S. Geological Survey state base map, 1965

CONVERSION TABLE

1 in (inch)	=	25.4 mm (millimeters)
1 mi^2 (square mile)	=	2.590 km^2 (square kilometers)
1 ft^3/s (cubic foot per second)	=	28.32 L/s (liters per second)
1 $ft^3/s.mi^2$ (cubic feet per second per square mile)	=	01093 ($m^3/s.km^2$) (cubic meters per second per square kilometer)

LOW-FLOW FREQUENCY OF MINNESOTA STREAMS

BY
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INTRODUCTION

The U.S. Geological Survey is making a continuing study of low-flow characteristics of streams in Minnesota in cooperation with the Minnesota Department of Natural Resources, Division of Waters. The purpose of the study is to define magnitude and frequency of low flows in streams to aid planning and management of stream systems for water supply, waste dilution, and other uses. A report by Lindskov (1977) listed low-flow characteristics for 161 continuous-record gaging stations and results of discharge measurements for about 600 partial-record stations.

This report presents, as a second part of the continuing study, the 7-day, 2-year low flow and 7-day, 10-year low flow at 161 continuous-record gaging stations and about 300 partial-record stations that had sufficient data for interpretation. Broad physiographic and climatic factors and hydrologic processes that affect low flows in the State are also discussed.

LOW-FLOW CHARACTERISTICS

Continuous-Record Gaging Stations

Data from all continuous-record gaging stations, active or discontinued, with 8 or more complete years of record through March 31, 1975, are used to compute expected annual low flows for specific recurrence intervals. Selected values shown on the large map are derived primarily from computer fits of the log Pearson Type III distribution to low-flow data. When the log Pearson theoretical distribution did not adequately represent the data, graphical fits were made. Figure 1 shows an example of the family of low-flow frequency curves developed from the records for one gaging station. In this report, the 7-day, 2-year recurrence interval and 7-day, 10-year recurrence interval low-flow estimates from these curves for each station are presented.

The reliability of low-flow frequency curves based on natural flows is related to the duration and sampling period of the record used. A sampling period representative of long-term flow characteristics is desired, but there is no way of knowing the representativeness of the available record. Inclusion in the sample of a period of substantial drought makes the record more representative of long-term low-flow events.

Low-flow frequency curves will change when computed for different sampling periods at any site. It follows, then, that the most meaningful comparisons between curves for different sites are made from records for the the same period for the sites being compared. Because there are obvious differences in curves computed using different periods of record for stations on the Red River of the North, the common period 1963-75 is selected from the records for those stations. For stations for which other than the total available record is used in the analysis, the period of record used is indicated on the map. For the few exceptions where the map values are not for the complete record, the user is reminded that both the map values and those for the entire record are given in Lindskov (1977).

Partial-Record Stations

Low-flow frequency values at partial-record stations included on the large map are estimated by relating discharge measurements at these stations to concurrent discharges at nearby continuous-record stations. The 7-day Q_2 and Q_{10} values for the streams at the continuous-record stations are transferred through the relation line to estimate 7-day Q_2 and 7-day Q_{10} values for the partial-record stations. This method is illustrated in figure 2 following the procedure outlined below.

Low-flow frequency values at the partial-record site 05200850 Turtle River near Pennington, Minn. (drainage area 165 mi^2) are to be estimated. The basis for development of the flow estimates are the seven discharge measurements made at the Turtle River site and concurrent flows at the continuous record gaging station 05212700 Prairie River near Taconite, Minn. (drainage area 360 mi^2). For each discharge measurement at the Turtle River site the concurrent flow at the Prairie River gage is determined, and the seven paired values are plotted using the respective scales in figure 2. A relation line is drawn through the plotted points as shown. The 7-day Q_2 and 7-day Q_{10} flow values for Prairie River are applied to the relation line, and corresponding flow-frequency estimates for the Turtle River site are read on the left. The user may want to try several continuous-record stations however, and select the one that correlates best with the low-flow partial record station.

Ordinarily those relations resulting in a slope near unity will be better defined and produce better estimates of low-flow characteristics than relation lines having other slopes. A unit slope relation indicates that the two streams have similar low-flow characteristics. More measurements are usually required to define relations between dissimilar streams than between similar ones, as the measurements will plot with more scatter.

Generally, only sites with a minimum of 5 low-flow measurements representing 4 or more years of record and having a correlation coefficient of at least +0.85 are included in this report. Other factors considered are the number of zero-flows recorded, the existence of data points near or between the estimated 7-day Q_2 and 7-day Q_{10}, the number of measurements eliminated for possibly representing some surface runoff, and differences between the relation line and the equal-yield line. When no flow is observed at the periodic measurement site, there obviously is no relationship to flow at a continuous record station at that time. Also, if a stream is observed several times to be dry, its value as a water source may not be worth considering. The observance of flows at or near the estimated 7-day Q_2 and 7-day Q_{10} values give added credibility and confidence to the relationship between those values at the periodic measurement site.

However, the observance of several occurrences of estimated 7-day Q_{10} flow in a few years at the partial record site would indicate that surface runoff may have been included in measurements made at the site or that a change, such as a large ground-water withdrawal, may have begun since the measurements were made. When surface runoff is included in supposedly base-flow measurements, there will probably be excessive scatter in the plot of measurements, as it is highly unlikely that surface runoff from two basins will occur in the same relation as ground-water outflow. When the relation line representing the measurements is not at unit slope or indicates widely differing yield rates, the two streams being compared obviously do not have similar low-flow characteristics.

DEFINITION OF TERMS

Base flow - Sustained or fair-weather flow. In most streams, that part of streamflow that is derived from ground water.

Partial-record station - A station where limited streamflow data are collected over a period of years.

Continuous-record station - A station where complete records of streamflow data are available.

7-day low flow - The lowest average discharge for seven consecutive days during a given length of time.

7-day Q_2 (7-day, 2-year low flow) - The annual minimum low flow for seven consecutive days that has a recurrence interval of 2 years. There is a 50 percent chance in any one year the minimum 7-day flow will be equal to or less than the 7-day, 2 year flow.

7-day Q_{10} (7-day, 10-year low flow) - The annual minimum low flow for seven consecutive days that has a recurrence interval of 10 years. There is a 10 percent chance in any one year the minimum 7-day flow will be equal to or less than the 7-day, 10 year flow.

Recurrence interval (return period) - Is the average time, in years, between flows that will at least equal in severity a given extreme during a period of many years. It cannot be predicted when a drought or a low flow of a given magnitude will occur, but the probable number of such events during a reasonably long period of time may be estimated. For example, a low-flow discharge of 2 ft^3/s having a recurrence interval of 10 years indicates that a discharge at least as low as 2 ft^3/s will occur as an annual minimum about 10 times in 100 years.

Cubic foot per second (ft^3/s) - A unit expressing the rate of discharge. One cubic foot per second is equivalent to the discharge of a stream whose channel is one square foot in cross sectional area and whose average velocity is one foot per second.

Cubic feet per second per square mile ($ft^3/s.mi^2$) - A unit expressing the average number of cubic feet of water per second flowing from each square mile of drainage area assuming that the runoff is evenly distributed in time and area.

Equal-yield line - A line on a graph constructed by plotting multiples of drainage area values for the partial-record station. On logarithmic paper this line is always at a 45-degree angle with the axes.

LOW-FLOW VARIABILITY

Factors That Influence Low Flow

Streamflow is sustained during extended periods of little or no precipitation primarily by water draining from the ground-water system. In river basins that have a large number of lakes, fair-weather streamflow can also be sustained at times by water released slowly from surface storage. Streamflow is classified as base flow when it is composed largely of discharge from ground-water storage. The low-flow periods analyzed for this study occurred mainly when base-flow conditions prevailed.

Geology and precipitation are two of the more influential factors affecting low flows in streams. The characteristics of the strata underlying an area greatly affect of base flow of streams in that area. Where the surface rocks are permeable, some precipitation infiltrates to temporary storage in the ground. Water discharges from temporary storage by seepage to streams and springs, and it may be pumped from wells. In areas of low permeability, infiltration is impeded, runoff is fast and little recoverable water is stored in the rocks; therefore, yields of shallow wells are small, and springs and streams cease to flow during dry spells. The geology of the basin determines the potential for ground-water storage, how readily water infiltrates and moves in soil and other earth material, and the rate at which it is released. Precipitation, of course, determines the amount of water available to the hydrologic system.

The magnitude of low flows and time of occurrence is also affected by the climate of the area. In Minnesota, annual minimum flows normally occur in late summer (August-September) or mid-winter (January-February). The minimums in late summer result from a combination of light precipitation and high evapotranspiration rates. In winter, most precipitation is in the form of snow which accumulates in the snow pack, and streamflow again is sustained primarily by discharge from ground water. In the northern half of the State, about two-thirds of the annual minimum events occur in winter.

Low-flow-frequency values for regulated streams have only limited use in estimating future events. The frequency values indicate past events, but there is no assurance that future regulation will be similar. Special low-flow studies are required for most regulated streams.

Statewide Variation in Low Flow

The magnitude of low flows per unit drainage area generally increases from west to east in Minnesota (fig. 3). Unit 7-day Q_{10} values generally range from 0 to 0.01 $ft^3/s.mi^2$ in the western half of the State, 0.1 to 0.2 $ft^3/s.mi^2$ in the southeast corner, and 0.01 to 0.1 $ft^3/s.mi^2$ in the remainder of the State. The low-flow values were determined for gage sites by studying and comparing drainage-basin characteristics such as the lithology and structure of rock formations. However, further studies of the hydrologic processes and physiographic factors are needed to delineate low-flow values more accurately.

Mean annual precipitation in Minnesota (fig. 4) also increases from west to east and is the principal meteorological influence that affects the magnitude of low flows.

Ground-water storage and aquifer permeability also influence low-flow patterns. In the western half of the State, glacial materials that are thick but of low permeability do not readily absorb and release water from storage. In the eastern part, more permeable but thin glacial materials with steep topography store and release moderate amounts of water from storage. The southeast corner is underlain by permeable limestone and sandstone units that yield large amounts of water to streams.

PRACTICAL APPLICATION

Low-flow frequency characteristics are useful in the management of water resources. The 7-day Q_2 is useful for a quick comparison of low flows in several streams. The 7-day Q_{10} is the most commonly used legal index of flow for pollution evaluation and control. The 7-day Q_{10} is also commonly used as an indication of the potential for water supply. The following example shows how low-flow characteristics from sites where discharge information is available can be used by local planners to evaluate the adequacy of streamflow:

> Suppose the Straight River near Park Rapids is being considered as a source of water supply. The map shows that the 7-day Q_{10} for station 05243725, Straight River near Park Rapids, is 38.5 ft^3/s. If this is more than the estimated need, the potential user will want to investigate further. If the amount is borderline for being adequate, other factors can be considered, such as the use of water from the stream, possibilities for building a reservoir, and a careful evaluation of the risk and consequences of a temporarily inadequate supply.

Supplemental information and interpretation are necessary to estimate low-flow frequencies at sites where little or no discharge information is available. Should the location of interest be on the same stream as either a continuous-record gaging station or a partial-record station included in this report, the 7-day Q_2 and 7-day Q_{10} values per square mile of drainage area may be suitable to transfer data to the location of interest. The drainage area at the site in question will have to be determined. If it differs by 20 percent or less from the drainage area at the gage, the 7-day Q_2 and 7-day Q_{10} values can be estimated by multiplying the values determined per-square-mile at the gage by the drainage area at the location of interest. If the drainage areas differ by more than 20 percent, or if the site is not on the same stream as the gage, it may be necessary to obtain several base-flow discharge measurements at the site and use the procedure outlined above with figure 2 to develop flow estimates.

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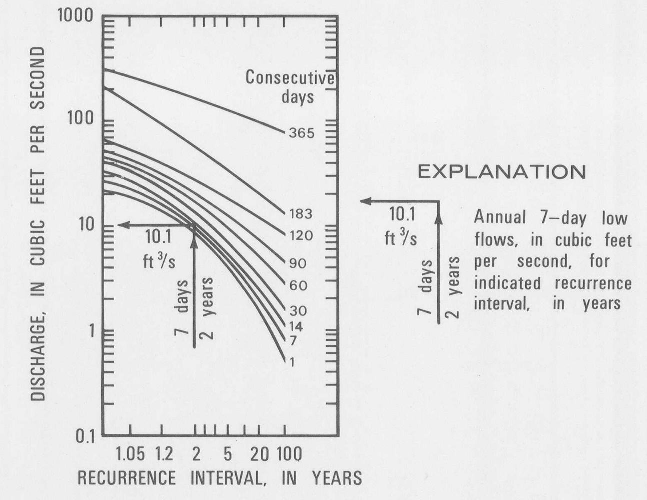

Figure 1.--Magnitude and frequency of annual low flows at Baptism River near Beaver Bay, Minnesota, 0414500

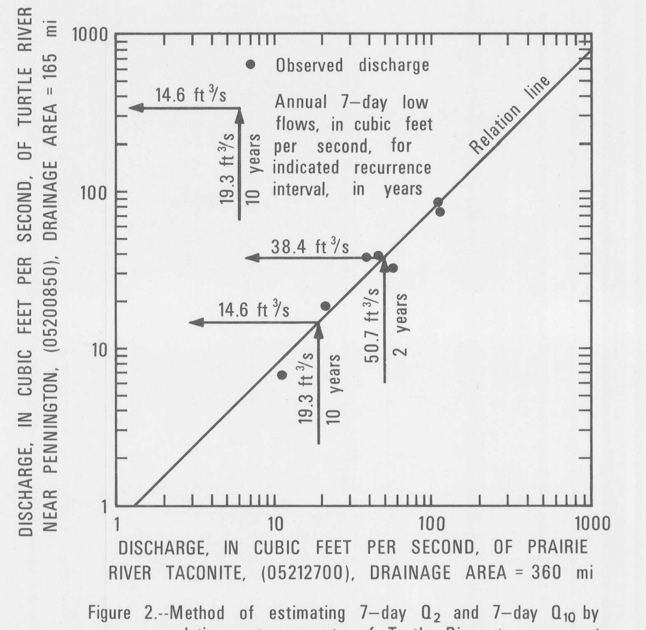

Figure 2.--Method of estimating 7-day Q_2 and 7-day Q_{10} by relating measurements of Turtle River to concurrent daily mean flow of Prairie River

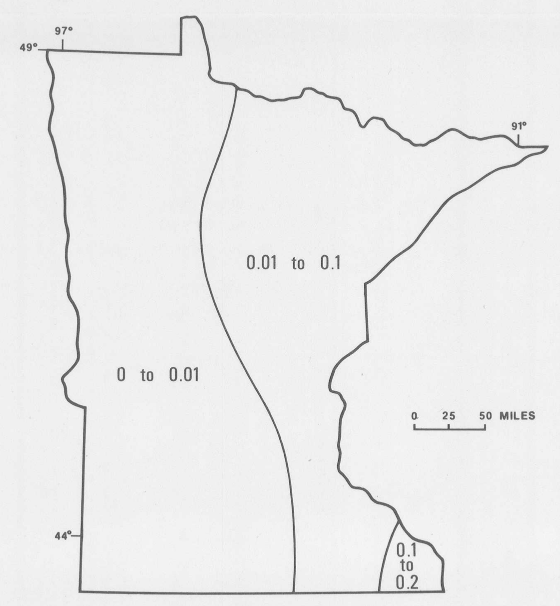

Figure 3.--Variation across the state in 7-day Q_{10} low flows, in cubic feet per second per square mile.

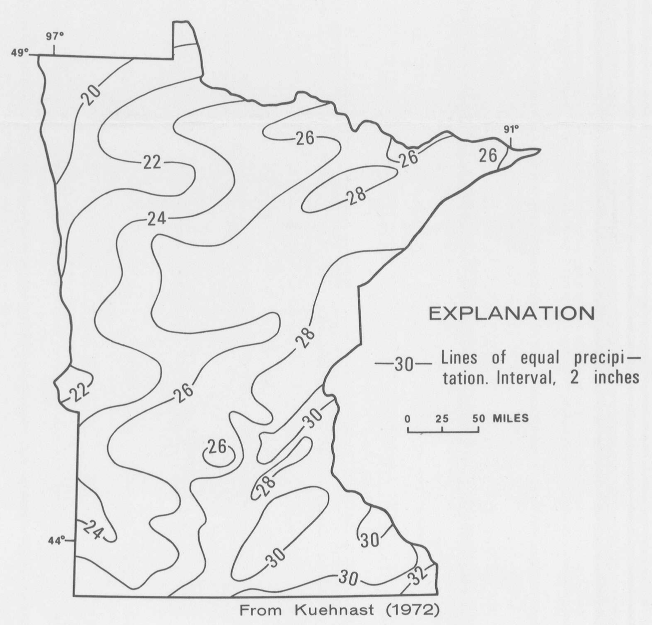

Figure 4.--Mean annual precipitation for 1951-70.

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